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Abstract

A model for H^-, D^- production by energetic particles reflecting from metal surfaces is discussed. The model employes the energy and angular distribution data derived from the Marlowe code. The model is applied to particles incident normally upon Cs, Ni, and Cs/Ni surfaces.

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A MODEL FOR H^-, D^- PRODUCTION BY HYDROGEN BACKSCATTERING FROM ALKALI AND ALKALI/TRANSITION-METAL SURFACES

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Hydrogen or deuterium particles backscattered from alkali or alkali/transition-metal surfaces are converted to negative ions with relatively high efficiency [1,2]. A model for H^-, D^- production by backscattered particles based upon resonant electron capture from the metal surface has been developed in previous papers [3,4,5,6]. Here we extend the model to a discussion of H^-, D^- production by particles backscattering from Cs, Ni, and Cs/Ni surfaces.

The negative-ion-secondary-emission-coefficient, NISEC, is a function principally of the reflected fraction, R_N, and the surface work function. The formation probability for negative ions by electron capture onto hydrogen atoms which are moving outward from the surface with velocity v is given by a function of the form $1-e^{-\alpha/v_\perp}$, where $v_\perp$ is the component of velocity perpendicular to the surface. The survival probability of negative ions moving away from the surface is $e^{-\beta/v_\perp}$; in the adiabatic limit the quantities α, β are functions of the surface work function but are independent of the isotopic mass of the backscattered particle.

For normal incidence, the distribution function of backscattered particles found using the Marlowe Monte Carlo code [7,8] can be factored according to

$$F(v,\theta)\, dv d\theta = 2\, f(v) \cos\theta\, dv d(\cos\theta) \quad , \tag{1}$$

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with

$$R_N = 2 \iint f(v) \cos\theta \, dvd(\cos\theta) \quad . \tag{2}$$

For any particular incident energy, E_i, the NISEC becomes

$$\mathrm{NISEC}(E_i) = 2 \iint f_i(v) \cos\theta \left[1-e^{-\frac{\alpha}{v\cos\theta}}\right] e^{-\frac{\beta}{v\cos\theta}} \, dvd(\cos\theta) \quad . \tag{3}$$

Integrating over $\cos\theta$, this reduces to an integral over velocity,

$$\mathrm{NISEC}(E_i) = 2 \int f_i(v) \, g\,(\alpha,\beta,v) \, dv; \tag{4}$$

with $a = \alpha/v$, $b = \beta/v$, $g(\alpha,\beta,v)$ is written

$$g(\alpha,\beta,v) = e^{-b}\left[(1-b)(1-e^{-a}) + ae^{-a}\right] + 0.57722\left[(a+b)^2-b^2\right]+(a+b)^2\ell n(a+b)$$
$$-b^2 \, \ell n \, b + \sum_{n=1}^{\infty} \frac{(-1)^n}{nn!} \left[(a+b)^{n+2}-b^{n+2}\right] \quad .$$

The velocity distributions of the backscattered particles, $f_i(v)$, are calculated using Marlowe. Experimental values for NISEC are inserted on the left hand side of equation (3), and a least-squares fit to the NISEC data is made treating α and β as adjustable parameters.

In figure one is shown a least-squares fit to the NISEC data for energetic deuterium incident normally on cesium, which is a low work function metal with ϕ = 1.9eV. The higher-energy circles are experimental data derived from D_2^+ collisions, the lower-energy circles obtained using incident D_3^+ ions [9]. The least-squares fit to the data are indicated by the crosses.

On the lower part of figure two is shown the NISEC data and fit for deuterium ions incident normally upon a polycrystalline nickel crystal. The work function for polycrystalline Ni is in the range = 4.6 to 5.1eV.

Shown in the upper portion of figure two is the experimental NISEC data and least-squares fit corresponding to the Cs adsorbate coverage on Ni that gives the maximum NISEC [9]. Note in particular that for this case the NISEC is increasing toward lower energies. The work function has not been measured directly but is believed to be lower than the bulk Cs value.

The quality of the fits shown in these figures is an indication that Marlowe is generating satisfactory velocity distributions, $f_i(v)$, and that the expression (3) is an adequate representation for NISEC in this energy and work function range.

Once having obtained the semi-emperical values for α, β from the least-squares fit it becomes possible to evaluate the formation, survival, and production probability. The production probability is defined here as the product of the formation and survival probabilities. These probabilities are shown in figure three and plotted as a function of the hydrogen perpendicular energy component. For deuterium the horizontal scale must be multiplied by two. Note that the production probability approaches sixty percent for a deuterium energy of 50eV. The production probability is the limiting value for NISEC if there were total reflection with little energy broadening.

The experimental NISEC data used in constructing the curves shown in figure three were obtained for incident deuterium energies in the range 170 to 550eV. An extrapolation of NISEC to lower energies using the semi-emperical α, β and expression (3) would represent a severe test of the Marlowe distributions and the formation model.

The angular distributions and energy distributions computed by Marlowe for normally incident deuterium on nickel at energies of 50, 100, and 220eV are shown in figures four and five, respectively. The diagonal line on figure four would correspond to a cosine distribution and is to be compared with the 50eV histogram. From figure five, observe that the peaking of the reflected energy distribution toward the incident energy becomes more pronounced for lower incident energies.

These reflected distributions are used in expression (3) to give the extrapolated values for NISEC shown in the final figure. The crosses are the data points used to find α, β, the circles are the extrapolated values. The increase in NISEC at lower energies is due largely to the increase in reflected fraction, R_N, and in part to the increase in the production probability.

In summary, we conclude that the Marlowe code generates accurate values for the reflected fractions, energy distributions, and angular distributions for incident energies down as low as 200 electron volts. The expression for NISEC, Eq. 2, provides for a satisfactory description of the negative ion formation for different surfaces with a broad range of surface work function. The extrapolation of our expression for NISEC to lower energies, shown in Figure six, will provide a severe test for both the Marlowe distributions and our formation model.

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FIGURE CAPTIONS

Fig. 1 The negative-ion-secondary-emission-coefficient, NISEC, as a function of deuterium energy for deuterons incident normally upon cesium.

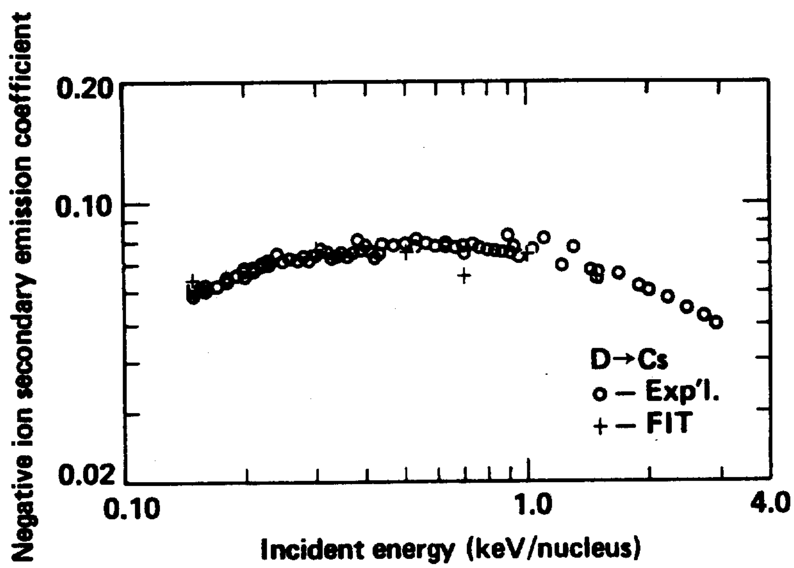
Fig. 2 The lower portion of the figure shows the NISEC data and least-squares fits for deuterons incident normally on nickel. The upper portion shows the NISEC and fits for deuterons incident normally upon Cs/Ni, for a Cs adsorbate coverage that exhibits a minimum work function and a maximum NISEC.

Fig. 3 The formation, survival, and production probabilities as a function the normal component of the incident hydrogen energy.

Fig. 4 The angular distribution histograms derived from Marlowe for normally incident deuterons at 50, 100, and 220eV. The diagonal line corresponds to cosine reflected distribution at 50eV. Solid curve - 50eV; long dashes - 100eV; short dashes - 220eV.

Fig. 5 The energy distribution histograms from Marlowe for normally incident deuterons at 50, 100, and 220eV. Solid curve - 50eV; dashed curve - 100eV; dotted curve - 220eV.

Fig. 6 The NISEC for normally incident deuterons on a minimum work function Cs/Ni surface. Crosses - exp. values; circled crosses - extrapolated values.



Negative ion secondary emission coefficient
0.20
0.10
0.02
0.10
1.0
4.0
Incident energy (keV/nucleus)
D→Cs
o – Exp'l.
+ – FIT

Figure 1

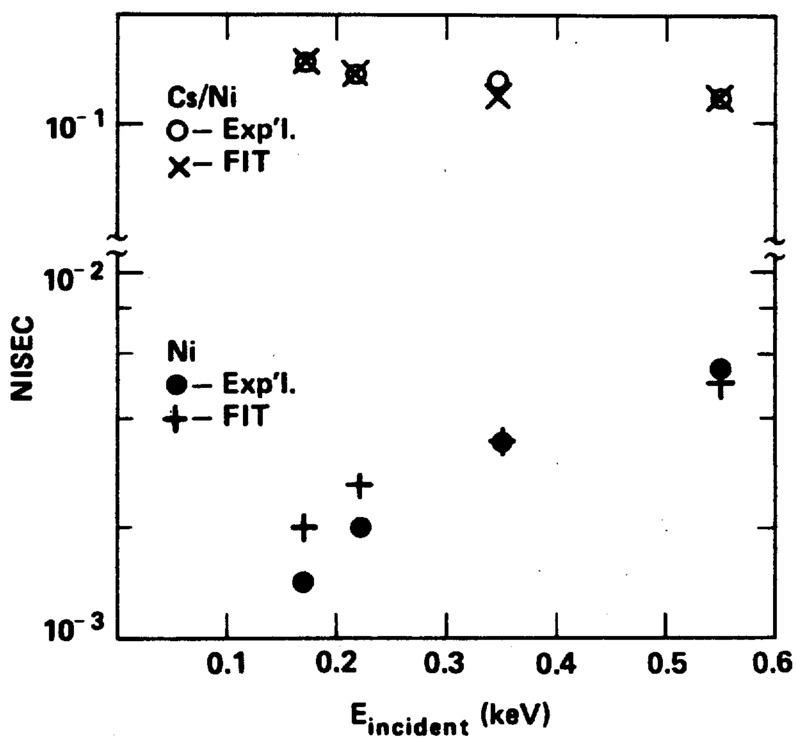
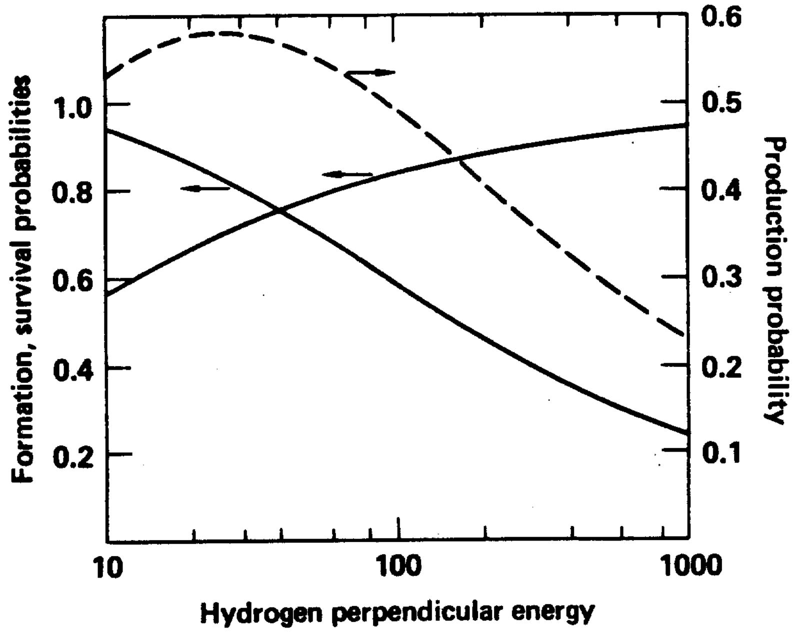
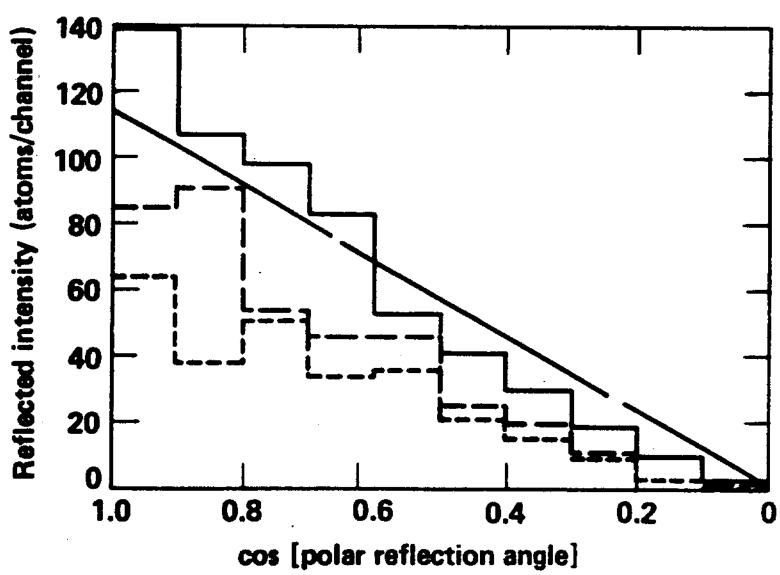

Cs/Ni
O– Exp'l.
X– FIT
Ni
●– Exp'l.
+– FIT
NISEC
10⁻¹
10⁻²
10⁻³
0.1
0.2
0.3
0.4
0.5
0.6
E incident (keV)

Figure 2



Formation, survival probabilities
Production probability
Hydrogen perpendicular energy
1.0
0.8
0.6
0.4
0.2
0.6
0.5
0.4
0.3
0.2
0.1
10
100
1000

Figure 3



Reflected intensity (atoms/channel)
140
120
100
80
60
40
20
0
1.0
0.8
0.6
0.4
0.2
0
cos [polar reflection angle]

Figure 4

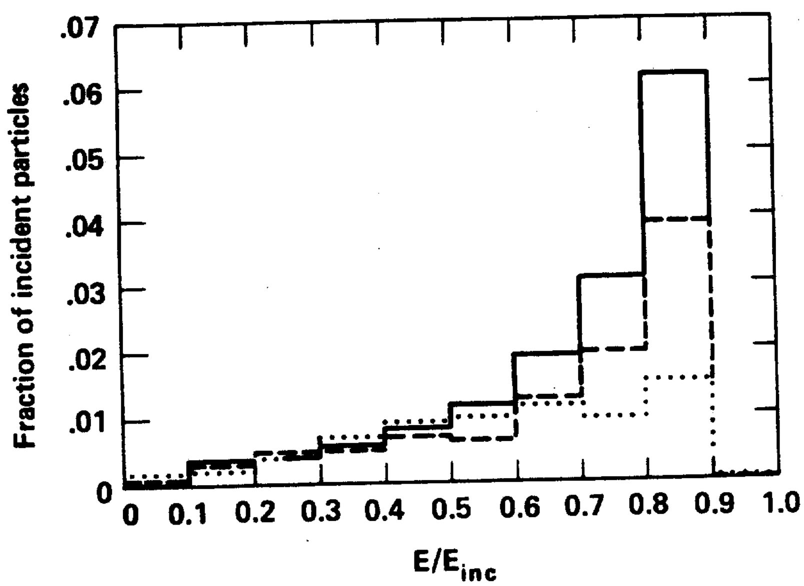

.07
.06
.05
.04
.03
.02
.01
0
Fraction of incident particles
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
E/E$_{inc}$

Figure 5

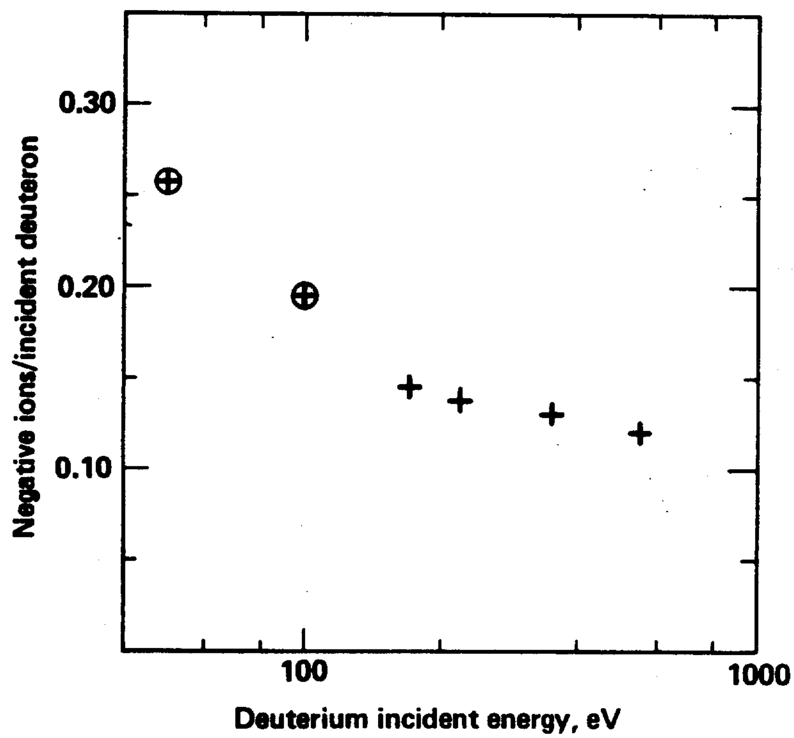

0.30
0.20
0.10
Negative ions/incident deuteron
100
1000
Deuterium incident energy, eV

Figure 6